

# Temporal and Spatial Aspects of Gas Release During the 2010 Apparition of Comet 103P/Hartley-2

M. J. Mumma (1), B. P. Bonev (1,2), G. L. Villanueva (1,2), L. Paganini (1,8), M. A. DiSanti (1), E. L. Gibb (3), J. V. Keane (4), K. J. Meech (4), G. A. Blake (5), R. S. Ellis (5), M. Lippi (6), H. Boehnhardt (6), and K. Magee-Sauer (7)  
(1) NASA Goddard Space Flight Center, Maryland, USA, (2) The Catholic University of America, Washington, D. C., USA, (3) University of Missouri – St. Louis, Missouri, USA, (4) University of Hawaii – Manoa, Hawaii, USA, (5) California Institute of Technology, California, USA, (6) MPI-Solar System Research, Germany, (7), Rowan University, New Jersey, USA, (8) NASA Postdoctoral Fellow, Maryland, USA (michael.j.mumma@nasa.gov / Fax: 001-301-614-6522)

## Abstract

We report measurements of eight primary volatiles ( $\text{H}_2\text{O}$ ,  $\text{HCN}$ ,  $\text{CH}_4$ ,  $\text{C}_2\text{H}_6$ ,  $\text{CH}_3\text{OH}$ ,  $\text{C}_2\text{H}_2$ ,  $\text{H}_2\text{CO}$ , and  $\text{NH}_3$ ) and two product species ( $\text{OH}$  and  $\text{NH}_2$ ) in comet 103P/Hartley-2 using high dispersion infrared spectroscopy. We present production rates for individual volatiles species, their mixing ratios relative to water, and their spatial distributions in the coma on multiple dates that span the interval Sept. – Dec. 2010. The production rates vary strongly with nucleus rotation, but the mixing ratios remain constant throughout the campaign. The released primary volatiles exhibit diverse spatial properties which favor the presence of separate polar and apolar ice phases in the nucleus, establish dust and gas release from icy clumps (and also, directly from the nucleus), and provide insights into the driver for the cyanogen (CN) polar jet. [9]

## 1. Introduction

Production rates of primary volatiles can change dramatically as orbital motion and nucleus rotation modulate the received insolation (and thus gas production) on long and short time scales, respectively. Moreover, the apparent mixing ratios in the coma may change if nucleus regions with distinct chemical compositions are exposed to sunlight sequentially, e.g., by nucleus rotation. And, spatial differences in the release of specific volatiles can occur if individual active vents contain material of diverse volatile character. Thus, measurements acquired through snapshots in time can be placed in a global context for the nucleus only if such behavior is characterized. Unfortunately, taking such snapshots of the composition from one or two observations has

provide that contextual perspective for Hartley-2, our investigation emphasized both the long-term and short-term behavior of gas release from the cometary nucleus.

## 1.1 Observations & Results

We acquired high-resolution near-infrared spectra of comet Hartley-2 using CRILES at the ESO VLT in late July, and with NIRSPEC at Keck-2 from late July through mid-December 2010. We successfully characterized volatile production with NIRSPEC on Sept. 18, Oct. 19 & 22, Nov. 16, and Dec. 16 & 17. The production rates vary strongly with nucleus rotation, but the mixing ratios remain constant throughout the campaign (Figure 2 [9]). A summary of water production rates and mixing ratios for all dates is presented in Table 2 [9]. The spatial profiles measured along slit are shown for  $\text{H}_2\text{O}$ ,  $\text{C}_2\text{H}_6$ , and dust on four dates, and for  $\text{HCN}$  and  $\text{CH}_3\text{OH}$  on two (Figure 3, [9]).

## 2. Discussion

The activity of Hartley-2 varied strongly with time. The short-term behavior is especially significant – the global production rates for water (the dominant volatile) changed by approximately a factor of two from 19 to 22 October, and again from 16 to 17 December (Figure 2b, Table 2 [9]). The production rates for water, ethane,  $\text{HCN}$ , and methanol varied in a manner consistent with nucleus rotation, similar to the behavior reported for the optical brightness of gas and dust in the coma and for radar images [6], CN jet activity [7], activity in  $\text{HCN}$  [4,5], and other phenomena linked directly to the nucleus [1,8]. The mixing ratios of trace gases measured by us (the ratios of production rates) are steady throughout the apparition (Figure 2c [9]), demonstrating that

Hartley-2 releases material that is rather homogeneous in the bulk average. Hartley-2 is the third comet for which periodic variation in production of primary volatiles has been demonstrated [2,3], and the first for which unambiguous association with nucleus rotation can be made through imaging.

## 2.1 Spatial Profiles & Ice phases

Ethane and water show quite distinct spatial profiles about the nucleus [9]. These profiles suggest strongly that ethane is escaping directly from the sunlit nucleus surface itself, while most other primary volatiles are released by vaporization of icy aggregates ('clumps') dragged outward by escaping CO<sub>2</sub> [1]. The very slow radial velocities of escaping icy aggregates (typically 0.3 m s<sup>-1</sup> [1]) imparts similar center-of-mass motion to the sublimating volatiles, which then adopt a nearly isotropic distribution determined by sublimation-endowed thermal velocities (several hundred m s<sup>-1</sup>) [9]. The released grains will be only poorly accelerated by the sublimating gas, owing to low gas densities near the sublimating clump, and will reach much smaller terminal velocities compared with grains released at the nucleus of a normal comet.

Although ethane and water exhibit distinct spatial profiles, the ethane abundance ratio (C<sub>2</sub>H<sub>6</sub>/H<sub>2</sub>O) changes little as the nucleus rotates, suggesting that these volatiles are segregated into two distinct ice phases (apolar and polar, respectively). It is not known whether CO<sub>2</sub> and ethane form a common apolar phase, or if two distinct apolar ice phases are present.

## 2.2 The CN North Polar jet

On Oct. 19, we aligned the slit along the CN North polar jet. The spatial profiles for water and methanol are symmetric along the slit while ethane and HCN are extended in the direction of the jet. HCN is much more extended in the jet direction than in the anti-jet direction, consistent with HCN outflow in the jet itself. The apolar volatile ethane is strongly enhanced in the jet direction, suggesting that apolar volatiles (e.g., CO<sub>2</sub>) could be driving the jet activity and that other (proposed) apolar volatile precursors of CN (such as di-cyanogen, C<sub>2</sub>N<sub>2</sub>) could be enhanced there as well.

## Acknowledgements

Keck telescope time was granted by NOAO (through the Telescope System Instrumentation Program funded by NSF), the University of Hawaii, and the California Institute of Technology. The European Southern Observatory granted VLT time. We gratefully acknowledge support by the NSF Astronomy and Astrophysics Research Grants Program (PI/co-PI Bonev/Gibb), by the NASA Astrobiology Institute (PI Meech, PI Mumma), by NASA's Planetary Astronomy (PI DiSanti, PI Mumma), Planetary Atmospheres (PI DiSanti; PI Villanueva), and Discovery (Meech) Programs, and by the German-Israel Foundation (D. Prialnik; M. Lippi).

## References

- [1] A'Hearn, M. F., et al. 2011, Science (in press).
- [2] Anderson, W. M., Ph. D. thesis, Catholic University of America, 2010.
- [3] Biver, N., Bockelée-Morvan, D., Colom, P., Crovisier, J., & Lecacheux, A., A&A 501, 359, 2009.
- [4] Biver, N., et al., private communication, 2010.
- [5] Drahus, M., et al., Ap. J. Lett., 734:L4 (6 pp), 2011.
- [6] Harmon, J. K., Nolan, M. C., Howell, E. S., & Giorgini, J. D., Ap. J. Lett., 734:L2 (4 pp), 2011.
- [7] Jehin, E., Manfroid, J., Hutsemekers, D., Gillon, M., & Magain, P. 2010, CBET, 2589.
- [8] Meech, K. J., et al., Ap. J. Lett., 734:L1 (9 pp), 2011.
- [9] Mumma, M. J., et al., Ap. J. Lett., 734:L7 (6 pp), 2011.